Enhanced Mars Landing Site Radar Observations with the Goldstone Solar System Radar

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Introduction: The Goldstone Solar System Radar (GSSR) has successfully collected radar echo data from Mars over the past 30 years. The older data pro-vided local elevation information for Mars, along with radar scattering information with global resolution (e.g. [1, 2]). Since the upgrade to the 70-m DSN antenna at Goldstone completed in 1986, Mars data has been collected during all but the 1997 Mars opposition. Radar data, and non-imaging delay-Doppler data in particular, requires significant data processing to extract elevation, reflectivity and roughness of the reflecting surface [3]. The spatial resolution of these experiments is typically some 20 km in longitude by some 150 km in latitude. The interpretation of these parameters while limited by the complexities of electromagnetic scattering, do provide information directly relevant to geophysical and geomorphic analyses of Mars.

Landing Site Assessment with Radar Data: The usefulness of radar data for Mars exploration has been demonstrated in the past. Radar data were critical in assessing the Viking Lander 1 site [4, 5] as well as, more recently, the Pathfinder landing site [6, 7]. In general, radar data have not been available to the Mars exploration community at large. One of us (Halde-mann) has recently finished a project funded by the Mars Exploration Directorate Science Office at the Jet Propulsion Laboratory (JPL) to reprocess to a common format the last twelve years worth of raw GSSR Mars delay-Doppler data in aid of landing site characteriza-tion for the Mars Surveyor Program. The radar data used were obtained since 1988 by the GSSR, and com-prise some 72 delay-Doppler radar tracks. Twenty-eight of the tracks lie in the latitude range proposed for landing sites for the 2003 Mars Exploration Rover (MER) and are listed in Tables 1, 2, and 3. The available data consist of Hagfors radar scattering model fits to the data every 0.1 degrees of longitude. The fit parameters are range (elevation), reflectivity (Fresnel), and surface roughness (rms slope) for each 20km x 150km resolution cell.

Interferometric delay-Doppler radar: Observing the radar echo with more than one receiver provides a means to remove the north-south delay-Doppler ambiguity. Thirteen of the 72 radar tracks in the recently re-assembled radar dataset are interferometric radar tracks (called out in Tables 2 and 3). The interferometric information has never been quantitatively processed, because the signal to noise is insufficient to constrain both the phases and the radar scat-tering parameters. The new topographic data from the Mars Orbiter Laser Altimeter (MOLA) on the Mars Global Surveyor (MGS) spacecraft offer the best means to analyze these unused data to make ra-dar maps that extend the radar properties coverage some 3 to 4 degrees beyond the sub-earth radar track. This would be a significant expansion of the dataset, and is all the more warranted as the radar spatial resolution improves away from the sub-Earth track (smaller range ring-Doppler strip inter-sections away from the sub-Earth track). At the outer edges the radar resolution cell is of the same order of size as the landing site ellipses for future missions (approx-imately 20 km diameter).

Table 1. GSSR Mars 1990 Observations

Date	Lat. (deg.)	Longitude (deg.) Rise	Set
14 Sept	-6.0	241.5	289.4
22 Sept	-4.8	160.0	214.1
29 Sept	-4.0	107.5	131.3
2 Oct	-3.8	51.3	109.9
12 Oct	-3.3	40.6	89.1
25 Oct	-3.6	226.1	242.1
27 Oct	-3.7	260.0	285.8
20 Nov	-7.6	64.7	82.0
15 Dec	-12.0	52.5	92.7
17 Dec	-12.2	22.4	77.8
24 Dec	-12.8	318.5	20.7
28 Dec	-13.0	289.4	6.0
30 Dec	-13.1	262.7	313.9

Table 2. GSSR Mars 1992 Observations

Date	Lat. (deg.)	Longitude (deg.) Rise	Set
15 Dec*	11.0	213.3	238.8
22 Dec*	10.0	191.7	218.6
31 Dec*	8.6	157.4	207.2

* Interferometric data recorded

The Mars observations in interferometric mode were made in such a way that they would have no im-pact on the normal ranging experi-ments. To that end, the range and frequency resolution were identi-cal to the normal ranging experiments with few exceptions. The baud was 6 microseconds over-sampled by two. The normal experiments have 35 range gates, but the inter-ferometer processing would nor-mally handle only about 33. The code had 63 elements, and no co-herent summing. So, the frequency coverage was 2645.5 Hz and processed in real time to 128 bins or about 20 Hz resolution. Spectra were recorded about every 5 sec-onds. The spectra included the power from Goldstone DSN antennas DSS-14 and DSS-13 and the cross power products. Thus, each frame contains about 16,896 float-ing point numbers. As with normal ranging, the front cap coverage is about 5 degrees. This is limited by aliases and not by the radar processing ca-pability (although these were at the limit).

The Doppler resolution is about 4.5 km (it varies a bit depending up-on the latitude of the sub-radar point, but this is as good as it gets. The range resolution depends on the angle from the subradar point, and some values are given in Table 2. There is no appreciable degra-dation of the resolution due to averaging. Because these data are over-sampled in range, we actually get the resolution indicated in Ta-ble 4. As to SNR, signal can normally be seen in all range gates for DSS-14. Just how much trouble the North-South aliases will be with the new processing is not yet resolved.

Table 3. GSSR Mars 1993 Observations

Date	Lat. (deg.)	Longitude (deg.) Rise	Set
2 Jan*	8.2	149.5	188.1
3 Jan*	8.0	89.5	175.7
5 Jan*	7.7	18.6	68.1
10 Jan*	6.8	14.3	109.9
14 Jan	6.0	307.2	353.8
21 Jan	5.0	238.3	273.5
23 Jan*	4.9	185.4	238.0
27 Jan*	4.4	136.2	179.1
31 Jan*	4.0	98.2	172.3
3 Feb*	3.9	101.2	168.4
7 Feb*	3.8	108.4	187.0
14 Feb*	3.7	8.0	113.9

* Interferometric data recorded

Table 4. Range Resolution

Theta (deg.)	Resolution (km)
1	35.4
2	17.2
3	11.5
4	8.6
5	6.9

Significance: Currently the data along 28 delay-Doppler radar tracks are available for MER landing site evaluation. The topogra-phic information these ra-dar data used to provide for Mars missions is now su-perceded by MOLA. However, the data from that instru-ment offer a means to bootstrap radar data to higher spatial resolu-tion. This offers the possibility of assessing the surface radar reflec-tivity and surface roughness over significant areas that meet the MER landing site selection criteria with data from 13 of the older tracks and all of the 18 tracks planned in 2001 (Table 5).

Table 5. Planned GSSR Mars 2001 Observations

Date	Lat. (deg.)	Longitude (deg.) Rise	Set	Target
3 May	-1.83	321	35	'Hematite'
4 May	-1.82	312	24	'Hematite'
5 May	-1.82	302	15	'Hematite'
17 May	-1.28	201	252	Elysium
19 May	-1.10	182	233	Elysium
28 May	0.00	93	141	'Stealth'
7 June	1.70	355	39	'Hematite'
8 June	1.88	346	29	'Hematite'
9 June	2.07	336	19	'Hematite'
15 June	3.24	276	317	Isidis/Syrtis
17 June	3.63	257	297	Isidis/Syrtis
22 June	4.56	206	245	Elysium
1 July	6.00	116	154	'Stealth'
2 July	6.13	106	144	'Stealth'
12 July	7.06	2	43	'Hematite'
14 July	7.18	346	23	'Hematite'
23 July	7.28	255	292	Isidis/Syrtis
28 July	7.07	203	241	Elysium

References: [1] Goldspiel J. M. et al. (1993) Icarus, 106, 346-364. [2] Moore H. J. and Thompson T. W. (1991) LPS XXI, 812-815. [3] Hagfors T., JGR, 102, 3779-3784. [4] Masursky H. and Crabill N. L. (1976) Science, 193, 809-812. [5] Tyler G. L. et al. (1976), Science, 193, 812-815. [6] Haldemann A. F. C. et al. (1997) JGR, 102, 4097-4106. [7] Haldemann A. F. C. et al. (1997) Eos Trans. AGU, 78, F404.

Figure 1. Radar tracks overlain on Mars Global Surveyor (MGS) Mars Orbiter Laser Altimeter (MOLA) altimetry and Viking MDIM for the Mars Exploration Rover landing latitude range. Blue tracks are existing GSSR delay-Doppler data, yellow and red tracks are existing and planned interferometric GSSR radar data respectively.
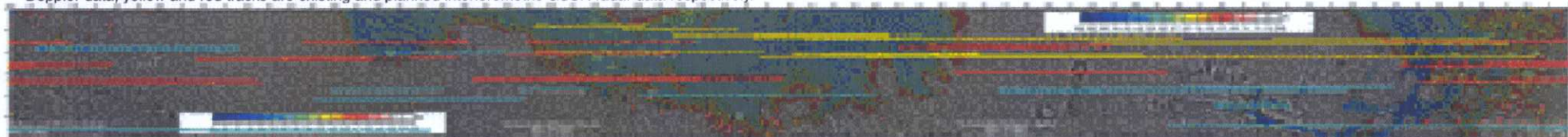

Figure 2. Radar tracks overlain on Mars geologic maps for the Mars Exploration Rover landing latitude range. Blue tracks are existing GSSR delay-Doppler data, yellow and red tracks are existing and planned interferometric GSSR radar data respectively.